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Passivity Based Control for PV Applications by Using a Buck Power Converter

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Abstract - The use of power converters for everyday applications is becoming more and more important. Current technological applications simultaneously demand a high level of precision and performance, so DC-DC converters have a very important role in systems requiring energy level conversion and adaptation. As part of the work of this paper, we are interested in an analysis of modeling and control law synthesis approaches to ensure stability and a certain level of performance in the entire operating domain. The objective of our research work is therefore to propose a control law whose synthesis is based on a formalized (modeling & control) approach with a view to obtaining a control law adapted to the operating point. The principles used are based on the control and observation by the theory of passivity for the synthesis of control law of buck power converter for PV Applications.

Keywords: Passivity Control, Buck Power Converter, PV, Simulation.

INTRODUCTION

The DC-DC switching converter works to periodically switch several operating modes. Due to the activation and deactivation of the switch, the converter is discrete although each mode of operation is linear and continuous. As a whole, the converter is a strongly nonlinear system. Compared to the linear method based on classical control theory, the nonlinear method for controlling the converter is more advantageous, and Passivity theory is an analytical technique for controlling nonlinear system (Wang et al., 2019), (Khaligh et al., 2006), (Shet, 2006), (Singh & Pandey, 2016). In most cases, a photovoltaic solar generator is not properly suited to an electrical load. Usually an adaptation stage, comprising one or more static converters, makes it possible to transform continuous electrical quantities into quantities adapted to the load. This stage can be controlled by one or more control laws in order to maximize the power produced by the generator.

In this work, Passivity control (PC) is applied for the purpose of tracking the MPP of the solar photovoltaic system. The electrical characteristic of the GPV which is approximated by a nonlinear model. The PC for controlling the Buck converter. Then the PI command is applied for the purpose of tracking the MPP of the same system. Finally we make a comparison for the two commands (Rakshit & Maity, 2018), (Sher et al., 2015), (Ryu et al., 2018), (Latif & Hussain, 2014).

Passivity control of buck converter

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The DC-DC switching converter works to periodically switch several operating modes. Due to the activation and deactivation of the switch, the converter is discrete although each mode of operation is linear and continuous. As a whole, the converter is a strongly nonlinear system. Compared with the linear method based on the classical control theory, the nonlinear method for controlling the converter is more advantageous, and the passivity theory is an analytical technique for controlling nonlinear system (Chuanjiang et al., 2006), (Zhang et al., 2018), (Kang et al., 2013), (Zhitao et al., 2010).
In general there are two different approaches, both based on the energy point of view, in order to model DC/DC converters in switching. The first approach uses the Lagrangian of the system while the second uses the Hamiltonian. Note that these methods are a priori very general and can also be used for the modeling of mechanical systems for example. Each of these models will allow us to apply the various control law synthesis methods using the tools of passivity. In this section we present the Euler-Lagrange model (Zhang et al., 2018).
In this section, we will introduce from a theoretical point of view, two classical methods for the synthesis of control laws, both based on passivity: The DI method and the IDAPBC method. In our work we use the DI method.
Consider a system whose general state model, Euler-Lagrange model, is of the form:

$$\mathcal{D}\dot{x} - \mathcal{J}x + \mathcal{R}x = \mathcal{E} \tag{1}$$

Where *D* is diagonal, *J* is antisymmetric and *R* is symmetric positive semi-definite, corresponding to the average Euler-Lagrange model. The purpose of the control law is to regulate the output of the system to a desired constant value. The methodology of the passivity control consists in making the closed loop (strictly) passive characterized by a desired storage function H_d.
We consider that a storage function of the system can be chosen according to the form $H = \frac{1}{2}x^T Dx$, which turns out to be the total energy of the lossless average model of the converter. Then we can offer as the desired storage function:

$$H_d = \frac{1}{2}\tilde{x}^T D\tilde{x} \tag{2}$$

Where $\tilde{x} \coloneqq x - x_d$ with x_d the desired value of *x* to be defined. Thus, by posing in (1):

$$x = \tilde{x} + x_d \tag{3}$$

$$R = R_d - H_{DI} \tag{4}$$

Where R_d represents the desired damping, the dynamics of the error $\tilde{x}$ of the system associated with the storage function (2) will be:

$$D\dot{\tilde{x}} - J\tilde{x} + R_d\tilde{x} = E - (D\dot{x}d - Jxd + Rx_d) + R_{D1}\tilde{x} = \psi \tag{5}$$

This dynamic is obtained after having injected the necessary damping R_{D1} so that $R_d = R + R_{D1}$ is symmetrical definite positive. However, having a positive definite damping matrix, it is possible to make the closed loop strictly passive by taking $\psi = 0$. The dynamics:

$$D\dot{\tilde{x}} - J\tilde{x} + R_d\tilde{x} = 0 \tag{6}$$

Will therefore be exponentially stable, because by taking the time derivative of H_d along the solutions of (5), since *J* is antisymmetric, we obtain:

$$\dot{H}_d = -\tilde{x}^T R_d\tilde{x} \le -\alpha H_d < 0 \qquad \forall\tilde{x} \ne 0 \tag{7}$$

Because R_d and *D* are two diagonal matrices with positive coefficients. It is then enough to fix $\psi = 0$ to obtain the dynamics of the control law, which gives:

$$D\dot{x}_d - Jx_d + R_{D1}\tilde{x} = E \tag{8}$$

Equation (7) then gives us an implicit definition of the control law. To obtain an explicit definition and since the command *u* is present in the matrix *J* or the vector *E*, we must then solve a system of n equations with *n* + 1 unknowns.

Thus, it will be necessary to choose one of the state variables of the system to set in order to be able to explicitly define the control law at u.
This procedure will be illustrated below in the context of the application to DC-DC converters. We will also see that the application of this method could lead, according to the fixed state variable, to instabilities of the control law, to equilibrium or even to too great a complexity, in particular for high order systems.
In this section, we will apply the passivity-based control law synthesis methods for the DC-DC converter type (Buck). We will then show the performances obtained with this control law in simulation for this type of converter.
The Euler-Lagrange mean state model for the Buck converter (Fig 1) is:

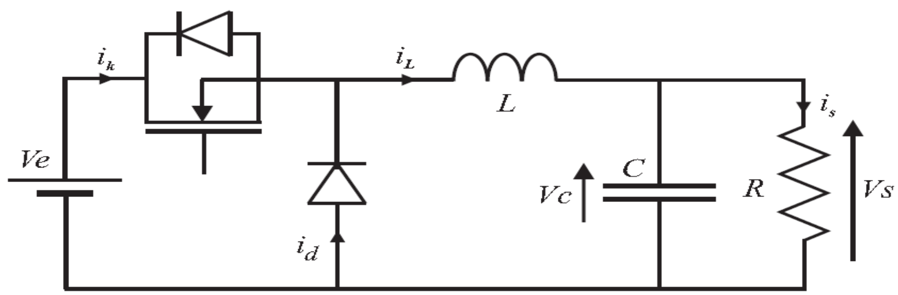

Figure 1: Buck converter diagram

$$\begin{pmatrix} L & 0 \\ 0 & C \end{pmatrix} \dot{x} = \begin{pmatrix} 0 & -1 \\ 1 & -\frac{1}{R} \end{pmatrix} x + u \begin{pmatrix} E \\ 0 \end{pmatrix} \tag{9}$$

Obtained by following the modeling method presented in section (9) the expression of the control law by the DI (damping injection) method then gives us the following system of equations, obtained by exploiting the relation (7):

$$\psi = 0 \Leftrightarrow \begin{cases} L\dot{x}_{1d} + x_{2d} - R_1(x_1 - x_{1d}) = uE \\ C\dot{x}_{2d} - x_{1d} + \frac{1}{R} x_{2d} = 0 \end{cases} \tag{10}$$

For a matrix:

$$R_{DI} = \begin{pmatrix} R_1 & 0 \\ 0 & 0 \end{pmatrix} \tag{11}$$

If we fix $x_{2d} = x_2^*$ with $x_2^* = v_{Cd}$ reference output voltage (assumed constant), we get the control law:

$$u = \frac{v_{Cd} - R_1\left(x_1 - \frac{v_{Cd}}{R}\right)}{E} \tag{12}$$

In the case of our study, we limit ourselves to the classic PI controller technique which successfully satisfies the control regulation of systems from the point of view of stability, speed and precision. The parameters of the Buck converter are given by Table 1.

Table 1. Buck Converter Parameters

L	C	E	R	R_1
220 μH	47 μF	20	11Ω	3Ω

The results of the simulation show that the response time and the speed of the passivity controlled buck converter (PC) are better in transient mode compared to the PI regulator, we can also say that the static error for both controls is acceptable. We notice that in general the performances of the passivity are better than those of the regulator

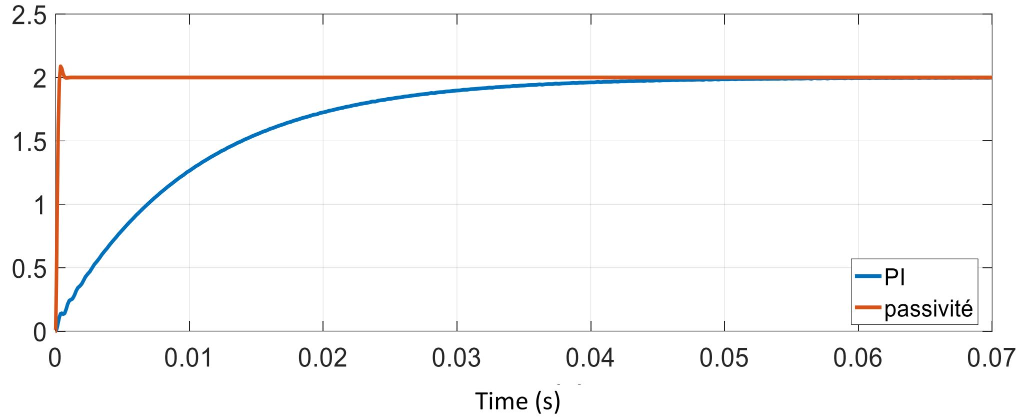

Figure 2: Output voltage (V)

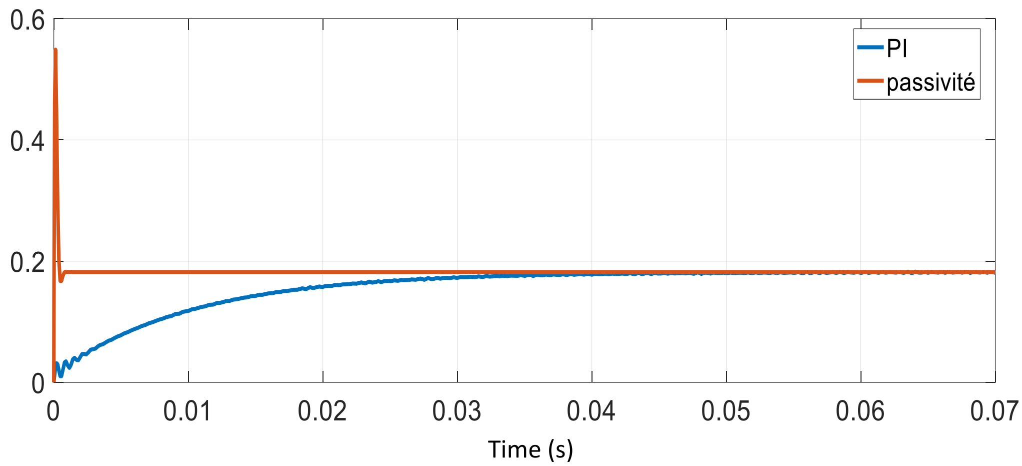

Figure 3: Current (A)

Passivity based MPPT control of buck converter

In most cases, a photovoltaic solar generator is not properly suited to an electrical load. Usually an adaptation stage, comprising one or more static converters, makes it possible to transform continuous electrical quantities into quantities adapted to the load. This stage can be controlled by one or more control laws in order to maximize the power produced by the generator. In this chapter, Passivity control (PC) is applied for the purpose of tracking the MPP of the solar photovoltaic system. The electrical characteristic of the GPV which is approximated by a nonlinear model. The PBC for controlling the BUCK converter. Then the PI regulator is applied for the purpose of tracking the MPP of the same system. Finally we make a comparison for the two commands. There is an operating point where the power output is maximum (figure 4). The optimization consists in achieving this point permanently by acting automatically on the load seen by the generator this load adaptation in principle is generally carried out using a static converter in the losses must be as low as possible and which can, moreover, perform a shaping function of an output generator, different attitudes can be envisaged as regards the control of the adapter.

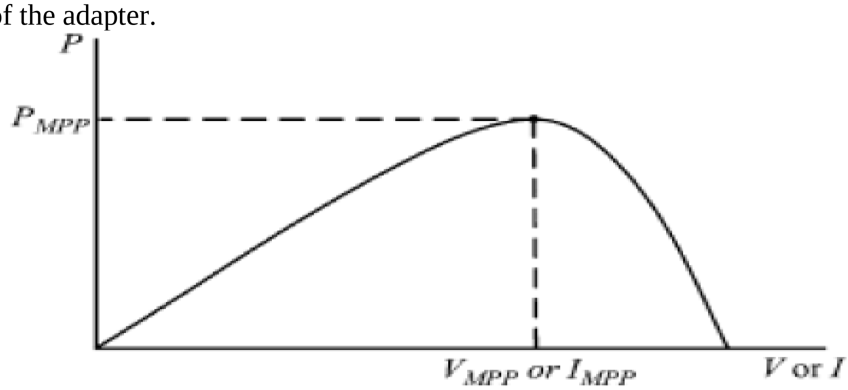

Figure 4: Power characteristic curve of GPV

In the literature, we can find different types of algorithms performing the search for PPM. In our work we are interested in the Perturb & Observ (P&O) method; we briefly recall the principle of this method. Figures 5 and 6 show the effect of increasing the power, caused by an increase in irradiation, which generates a deviation of the maximum power point MPP for both controls the voltage, is almost constant. Once the irradiation stabilizes, the power returns to its stable state with fewer disturbances to the passivity. The latter made it possible to obtain a very short response time and better dynamic performance with negligible disturbances compared to a PI regulator

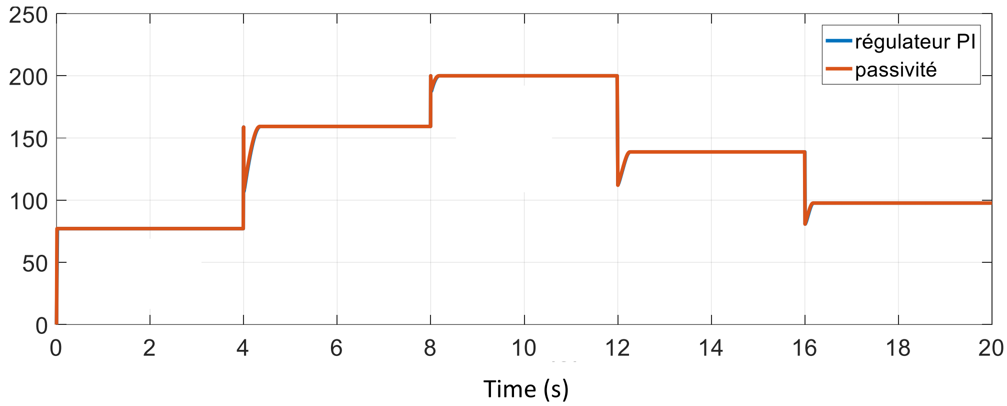

Figure 5: Power (W)

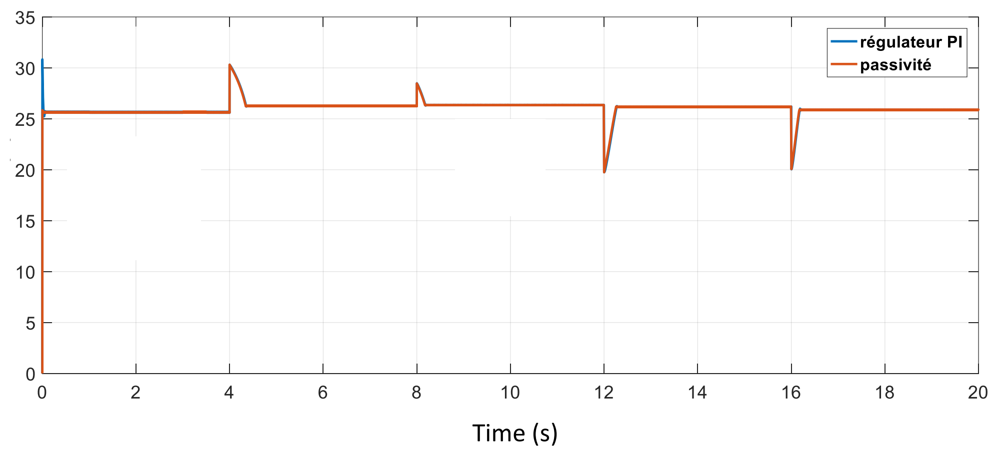

Figure 6: Output voltage (V)

Figures 7 and 8 show that the increase in temperature implies a decrease in the maximum power for the two controls with decrease in the voltage, which causes a displacement of the point of maximum power. Stabilizes, the power returns to its stable state.

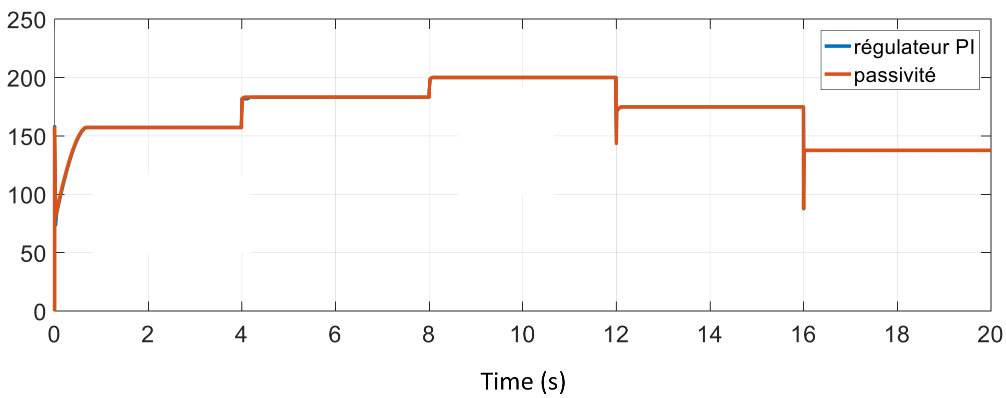

Figure 7: Power (W)

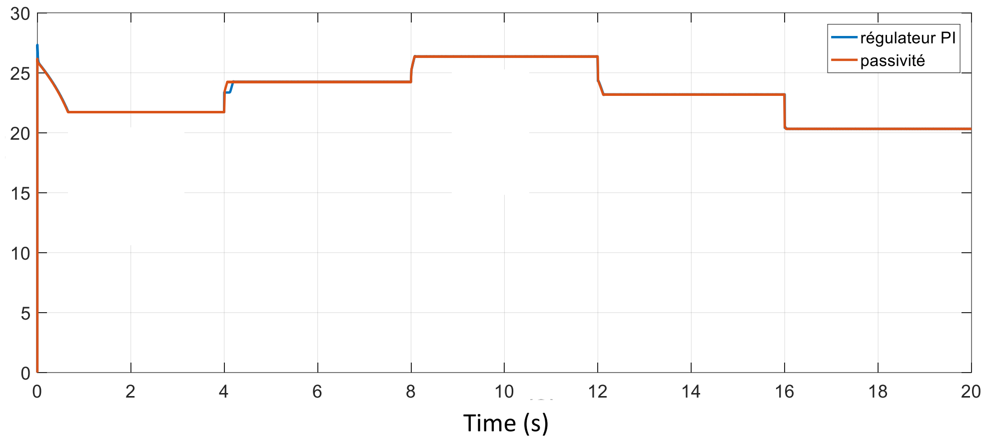

Figure 8: Output voltage (V)

CONCLUSION

We have presented in this work MPPT Control Based on Passivity and MPPT Control on the PI regulator. Finally, the application of the passivity control (PC) for the pursuit of the MPP shows its efficiency and its robustness compared to the PI regulator in terms of the speed and the reduction of the disturbances vis-à-vis climatic variations as well only system settings.

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